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(54) **An apparatus for driving a semiconductor laser device.**

(57) An apparatus for driving a semiconductor laser device (1) comprises current supply means (4) and control means (24) for controlling the current (I_F) supplied to the laser device (1) by the current supply means (4). The control means (24) include a memory. Two values (P_{o1}, P_{o2}) of the optical output (P_o) of the laser device (1) are stored in the memory. The values (I_{F1}, I_{F2}) of the current (I_F) required to obtain the stored values (P_{o1}, P_{o2}) of the optical output (P_o) of the laser device (1) are also stored in the memory. The control means (24) is able to calculate the current (I_{F3}) required to obtain a predetermined optical output (P_{o3}) from the laser device (1) from the values (I_{F1}, P_{o1}, I_{F2}, P_{o2}) stored in the memory.

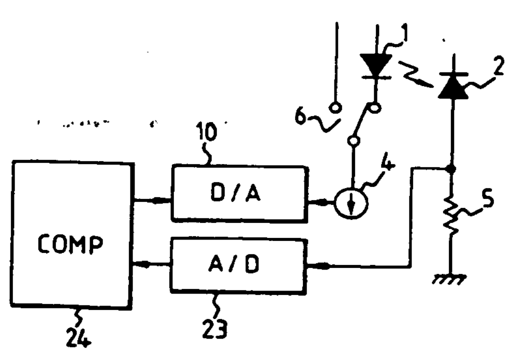


FIG.8

EP 0 497 431 A1

BACKGROUND OF THE INVENTION

1. Field of the invention:

This invention relates to a method of driving a semiconductor laser device and an apparatus for driving a semiconductor laser device.

2. Description of the prior art:

When driving a semiconductor laser device to obtain a laser beam, a forward current I_F is supplied to a pn junction in the laser device. The relationship between the forward current I_F and the optical output P_O of a semiconductor laser device is not linear. As the forward current I_F supplied to a semiconductor laser device increases, the laser device begins to oscillate a laser beam at a certain level of the current (a threshold current I_{th}). As the forward current I_F increases further, the laser output P_O also increases. Figure 1 shows an example of the relationship between the forward current I_F and the optical output P_O of a semiconductor laser device.

The level of a threshold current I_{th} and the rate of change in an optical output P_O with respect to the changes in a forward current I_F are not constant but vary according to an ambient temperature or to the individual semiconductor laser device. Such a rate of change in an optical output P_O is called a differential efficiency η.

When a semiconductor laser diode is driven at an optical output of a constant level, the system shown in Fig. 2 is generally used. In this system, a semiconductor laser diode **1** is driven by a current source **4** which is controlled by the output of an amplifier **3**. The optical output of the laser diode **1** is monitored by a photodiode **2**, and is converted into voltage by a resistor **5**. The voltage is applied to one input terminal of the amplifier **3**. The system shown in Fig. 2 constitutes a negative feedback loop. A reference voltage V_{ref} is applied to the other input terminal of the amplifier **3** so that the optical output of the laser diode **1** is controlled to have a predetermined level corresponding to the reference voltage V_{ref}.

The system shown in Fig. 2 is used for obtaining a constant optical output of a predetermined level. In certain kinds of application of a semiconductor laser diode, such as laser printers or optical communication, a semiconductor laser diode producing a constant optical output of a predetermined level is turned on and off at a high speed. Figure 3 shows an example of a system used for such an application.

The system of Fig. 3 comprises, in addition to the components in the system of Fig. 2, an analog switch **7** and a capacitor **8** which constitute a sample-hold circuit. The system of Fig. 3 further comprises a high-speed switch **6** and a buffer amplifier **9**. The operation of the system of Fig. 3 will be described. First, the switch **6** is set to the right position, and the switch **7** is turned on to obtain an optical output of a predetermined level corresponding to the reference voltage V_{ref}. Thereafter, the switch **7** is turned off. At this stage, the voltage applied to the amplifier **9** is held at the voltage level of the capacitor **8** so that the driving current supplied to the laser diode **1** is maintained to be constant. Then, the switch **6** is turned off and on at a high-speed, resulting in a high-speed switching of the optical output of a constant level.

With the system shown in Fig. 3, it is difficult to maintain the optical output at a constant level for a long period of time because the voltage of the capacitor **8** is an analog value. The system illustrated in Fig. 4 has been proposed to solve this problem, i.e., the system can maintain the optical output at a constant level for a long period of time.

The system of Fig. 4 is not provided with the sample-hold circuit (the analog switch **7** and capacitor **8**) and the buffer amplifier **9** which are used in the system of Fig. 3, but comprises an up/down counter **11,** a D/A converter **10,** and an oscillator **12.** In the system of Fig. 4, the amplifier **3** functions as a comparator. When the output of the comparator **3** is "HIGH", the up/down counter **11** counts up the output pulses of the oscillator **12.** When the output of the comparator **3** is "LOW", in contrast, the counter **11** counts down the output pulses of the oscillator **12**. The output of the counter **11** is converted into an analog value corresponding to the forward current I_F by the D/A converter **10**. When the switch **6** is set to the right position, the forward current I_F from the current source 4 is supplied to the semiconductor laser diode 1 to drive the laser diode 1. The system of Fig. 4 constitutes a negative feedback loop so that the optical output of the laser diode 1 is regulated at a constant value corresponding to the reference voltage V_{ref}. An error which corresponds to one pulse of the output of the oscillator 12 may occur in the level of the optical output.

One problem is the fact that the I_F-P_O characteristics of a semiconductor laser diode are such that, if a foward current I_F is less than the threshold current I_{th}, laser oscillation does not occur. Accordingly, if the forward current I_F is less than the threshold current I_{th}, it cannot be used for control in driving the laser

diode. For this reason, the quantization error of the optical output P_O is greater than the quantization error of the forward current I_F, resulting in less accuracy in controlling the optical output P_O.

The above-mentioned problem will be discussed in more detail. Figure 5 (a) shows a relation between an input (digital codes) and an output (forward current I_F) of D/A converter which are usually used in a conventional system such as shown in Fig. 4. Figure 5 (b) shows a relation between optical outputs P_O of laser diode and digital codes in the conventional system of Fig. 4 which employs a D/A converter having the linear characteristics shown in Fig. 5 (a). The digital codes corresponding to values lower than the threshold current I_{th} of a laser diode do not contribute to the optical output of the laser diode. As shown in Fig. 5 (b), therefore, the range of the codes which are effective in practical use is restricted, resulting in a reduced effective resolution of the D/A converter 10. In Fig. 5 (b), "W_q" indicates a quantization width of the optical output P_O.

A further problem is as follows:- in the system of Fig. 4 an optical output of a desired level can be obtained by applying a reference voltage V_{ref} which corresponds to the desired optical output level and closing the negative feedback loop (hereinafter, this process is referred as "calibration"). As the calibration is not directly related to the driving operation of the laser diode 1, it is difficult to employ the system of Fig. 4 in an apparatus in which the optical output level should be changed very frequently. In an optical magnetic disk recording apparatus, for example, the optical output is changed into three levels (reading, erasing, and recording level).

CA-B-1 210 070, on which the preamble of claim 1 is based, discloses an apparatus for driving a semiconductor laser device, said apparatus comprising:- current supply means; and control means for controlling a current supplied to said laser device by said current supply means, said control means comprising a memory means, said memory means being adapted to store a first current value and a first value of an optical output of the laser device, said first value of said optical output of the laser device being obtained when said first current value is supplied to the laser device and to store a second current value and a second value of said optical output of the laser device, said second value of said optical output of the laser device being obtained when said second current value is supplied to the laser device.

However, CA-B-1 210 070 does not disclose an apparatus adapted to calculate the current required to obtain a predetermined optical output from the laser device from the values stored in the memory means.

SUMMARY OF THE INVENTION

According to the present invention there is provided an apparatus for driving a semiconductor laser device according to the preamble of claim 1, said apparatus for driving a semiconductor laser device being characterised in that said control means is adapted to calculate a third current value corresponding to a predetermined optical output from said laser device, said third current value being calculated from said stored values.

According to the present invention there is further provided an apparatus for driving a semiconductor laser device to develop a predetermined constant optical output, said apparatus comprising means for monitoring an optical output of the laser device and generating a signal which is representative of the optical output and a feedback loop comprising: - comparing means for comparing said signal representative of the optical output with a reference value and providing an output signal, said output signal depending on a comparison of said signal representative of the optical output with said reference value; counting means for developing a digital signal for said output signal being provided from said comparing means; D/A converting means for developing a control signal in response to said digital signal; and first current supply means for driving the laser device at said predetermined optical output in response to said first control signal; said apparatus being characterised in that it further comprises second current supply means for supplying current to said laser device, said second current supply means not being within said feedback loop.

Thus, the invention described herein makes possible the objectives of (1) providing an apparatus for driving a semidconductor laser device which can control an optical output level with high accuracy; and (2) providing an apparatus for driving a semiconductor laser diode which can change the optical output to desired levels at a very high frequency.

BRIEF DESCRIPTION OF THE DRAWINGS

This invention may be better understood and its numerous objects and advantages will become apparent to those skilled in the art by reference to the accompany drawings as follows:

Figure 1 is a graph showing a relation between a forward current I_F and an optical output level of a laser

diode.

Figure 2 is a diagram showing an example of a conventional apparatus.

Figure 3 is a diagram showing another example of a conventional apparatus in which a sample-hold circuit is used and the optical output of a laser diode is switched at a high frequency.

Figure 4 is a diagram showing a further example of a conventional apparatus in which a D/A converter is disposed in a feedback loop.

Figures 5(a) and 5(b) are respectively a graph showing a relation between digital codes and the forward current and a graph showing a relation between digital codes and the optical output of the laser diode, according to the conventional example shown in Fig. 4.

Figure 6 is a diagram showing a further embodiment of the invention.

Figures 7(**a**) and 7 (**b**) are graphs showing relations between digital codes and the optical output of the laser diode, according to the embodiment shown in Fig. 6.

Figure 8 is a diagram of an embodiment of the invention.

Figure 9 is a diagram of a further embodiment of the invention.

Figure 10 is a graph for illustrating the operation of the embodiments shown in Figs. 8 and 9.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figure 6 shows an embodiment of the invention. The configuration of the system shown in Fig. 6 is similar to that of the system of Fig. 4 except that a second current source **4a** is provided. The current source **4a** supplies an offset current I_{OS} of a certain level to the laser diode **1**, i.e., the laser diode **1** is driven by the sum of the forward current I_F and the offset current I_{OS}. Figures 7 (a) and 7(b) show the relations between digital codes of the D/A converter **10** and optical outputs P_O of the laser diode **1** when the offset current I_{OS} is greater or smaller than the threshold current I_{th}, respectively. When the offset current I_{OS} is smaller than the threshold current I_{th}, the number of the codes which are ineffective in the control of the optical output of the laser diode **1** is small (Fig. 7 (b)). When the offset current I_{OS} is greater than the threshold current I_{th}, there is no code which is ineffective in the control of the optical output of the laser diode **1** (Fig. 7 (a)). Consequently, the quantization widths W_3 (Fig. 7 (a)) or W_4 (Fig. 7(b)) in the system of Fig. 6 is narrow, compared to those obtained by the system of Fig. 4 even when the D/A converters **10** used in both the systems have the same resolution characteristics, resulting in an improved effective resolution of the D/A converter **10** and also in a very accurate control of the optical output.

Figure 8 shows diagramatically a further embodiment of the invention. In the system of Fig. 8, the monitor signal detected by the circuit consisting of a photodiode **2** and a resistor **5** is converted to digital codes by an A/D converter **23**, and sent to a computing means **24**. The computing means **24** has a memory. The digital codes from the A/D converter **23** are processed in the computing means **24**. The obtained result is fed back to a laser diode **1** through a D/A converter **10**, a current source **4**, and a switch **6**.

The system of Fig. 8 will be described more specifically with reference to Fig. 9. The system of Fig. 9 is constructed so that an optical output of any desired level can be obtained only by conducting the calibration two times. In the example, the A/D converter **23** consists of a comparator **3**, an analog switch **15**, an up/down counter **11**, and an oscillator **12**. In the system of Fig. 9, the relationship between the optical output P_O and a forward current I_F can be calculated by the following Equation (1):

$$P_O = \eta I_F + \zeta \qquad (1)$$

For example, the calibration is conducted for two optical output levels P_{O1} and P_{O2} to obtain an amount of the forward current I_F for each output level. When a value I_{F1} is obtained for the output level P_{O1} and a value I_{F2} for the output level P_{O2}, the constants can be calculated from the following Equations (2) and (3):

$$\eta = \frac{P_{O2} - P_{O1}}{I_{F2} - I_{F1}} \quad \text{..... (2)}$$

$$\zeta = \frac{P_{O1}I_{F2} - P_{O2}I_{F1}}{I_{F2} - I_{F1}} \quad \text{..... (3)}$$

Therefore, a level I_{F3} of the forward current which is required for obtaining an optical output of any desired level P_{O3} can be calculated from the Equation (1). This is illustrated in Fig. 10.

The operation of the system of Fig. 9 will be described. The values of the two levels P_{O1} and P_{O2} at each of which the calibration is to be conducted are previously stored in the memory of the computing means **24**. The calibration is done by applying the reference voltage V_{ref1} or V_{ref2} to the comparator 3. The reference voltages V_{ref1} and V_{ref2} correspond to the optical output levels P_{O1} and P_{O2}, respectively. The output of the counter 11 obtained at each calibration is stored in the memory of the computing means **24.** The stored output of the counter **11** corresponds to the forward current I_{F1} or I_{F2} by which the laser diode **1** is driven to emit the optical output of the level P_{O1} or P_{O2}. From the stored data, η and ζ are calculated using the Equations (2) and (3). Then, the system conducts an operation process of driving the laser diode **1**. When an optical output of another level P_{O3} is to be emitted, the computing means **24** calculates the value of a forward current I_{F3} which is necessary for obtaining the desired optical output level P_{O3}. This is calculated from Equation (1), and is sent to the D/A converter **10.** As easily understood from the above, the feedback loop from the photodiode **2** to the counter **11** is not necessary when driving the laser diode **1**. Even when the desired optical output level P_{O3} is rapidly changed, therefore, the system can precisely drive the laser diode **1** at the desired level P_{O3}. The calibration may be conducted when an operating condition affecting the optical output level (for example, an ambient temperature) varies.

As seen from the above-mentioned description of the preferred embodiments, a D/A converter having low resolution which can be easily produced at a low cost can be used in an apparatus of the present invention. Therefore, an apparatus of the present invention can be easily manufactured a low cost and is easily integrated.

It is understood that various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be construed as encompassing all the features of patentable novelty that reside in the present invention, including all features that would be treated as equivalents thereof by those skilled in the art to which this invention pertains.

Claims

1. An apparatus for driving a semiconductor laser device (1), said apparatus comprising:-

current supply means (4); and

control means (24) for controlling a current (I_F) supplied to said laser device (1) by said current supply means (4), said control means (24) comprising a memory means,

said memory means being adapted to store a first current value (I_{F1}) and a first value (P_{o1}) of an optical output of the laser device (1), said first value (P_{o1}) of said optical output of the laser device (1) being obtained when said first current value (I_{F1}) is supplied to the laser device (1) and to store a second current value (I_{F2}) and a second value (P_{o2}) of said optical output of the laser devic (1), said second value (P_{o2}) of said optical output of the laser device being obtained when said second current value (I_{F2}) is supplied to the laser device (1);

said apparatus for driving a semiconductor laser device (1) being characterised in that said control means (4) is adapted to calculate a third current value (I_{F3}) corresponding to a predetermined optical

output (P_{o3}) from said laser device, said third current value being calculated from said stored values (I_{F1}, P_{o1}, I_{F2}, P_{o2}).

2. An apparatus for driving a semiconductor laser device (1) according to claim 1 and further comprising:-
means (2) for monitoring said optical output (P_o) of the laser device (1) and generating a signal representative of the optical output (P_o) of the laser device (1);
comparing means (3) for comparing said signal representative of the optical output with a reference value and providing an output signal, said output signal depending on a comparison of said signal representative of the optical output with said reference value;
counting means (11) for developing a digital signal for said output signal provided from said comparing means (3); and
D/A converting means (10) for developing a control signal to control said current supply means (4) in response to said digital signal;
said comparing means (3), said counting means (11), said control means (24), said D/A converting means (10) and said current suppply means (4) comprising a feedback loop.

3. An apparatus for driving a semiconductor laser device (1) according to claim 1 or 2, wherein said control means calculates said third current value (I_{F3}) using the equation

$$P_o = \eta I_F + \zeta \qquad (1)$$

wherein the constants η and ζ are calculated using said stored values (I_{F1}, P_{o1}, I_{F2}, P_{o2}).

4. An apparatus for driving a semiconductor laser device (1) to develop a predetermined constant optical output, said apparatus comprising means (2) for monitoring an optical output of the laser device (1) and generating a signal which is representative of the optical output and a feedback loop comprising:-
comparing means (3) for comparing said signal representative of the optical output with a reference value and providing an output signal, said output signal depending on a comparison of said signal representative of the optical output with said reference value;
counting means (11) for developing a digital signal for said output signal being provided from said comparing means (3);
D/A converting means (10) for developing a control signal in response to said digital signal; and
first current supply means (4) for driving the laser device (1) at said predetermined optical output in response to said first control signal;
said apparatus being characterised in that it further comprises second current supply means (4a) for supplying current to said laser device (1), said second current supply means (4a) not being within said feedback loop.

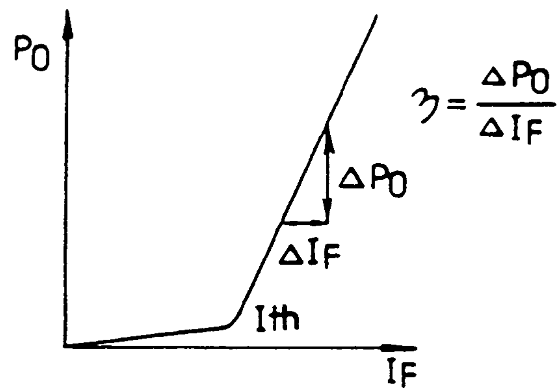


FIG. 1

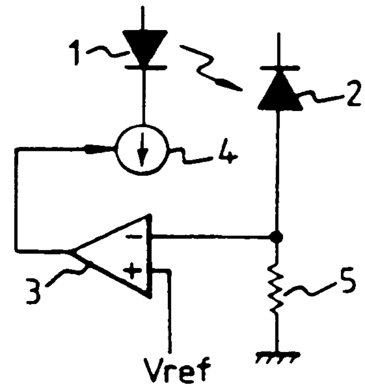


FIG. 2

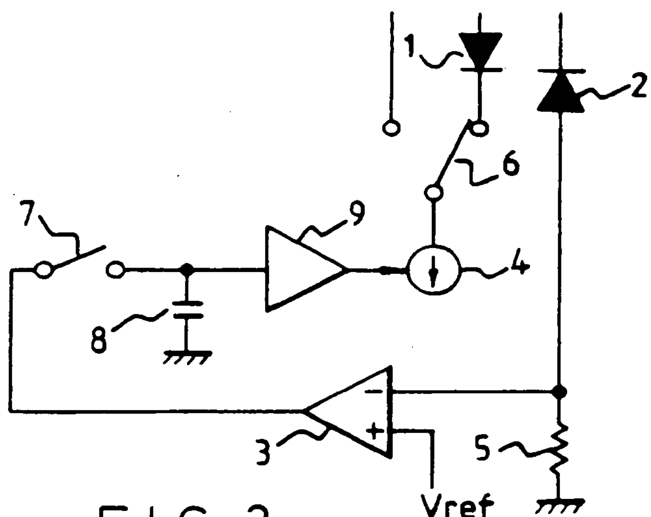


FIG. 3

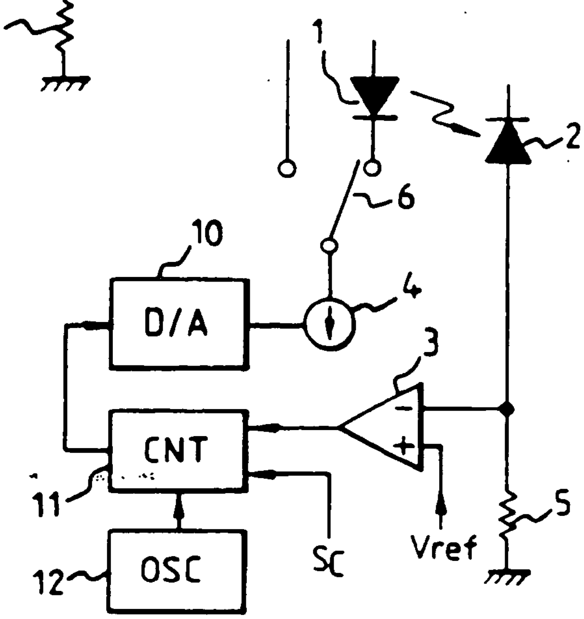


FIG. 4

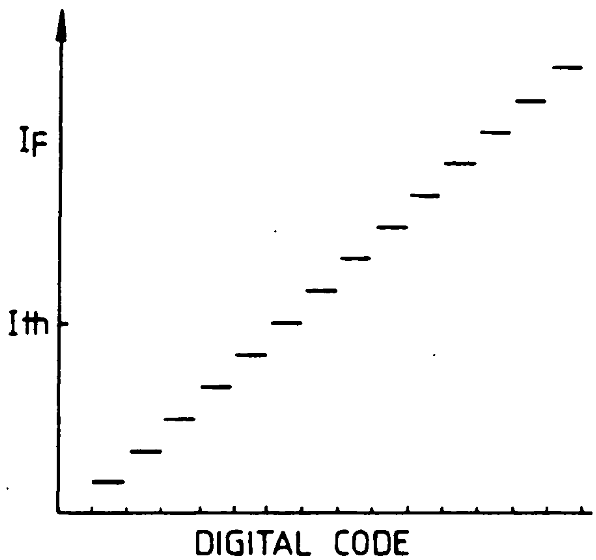


FIG.5a

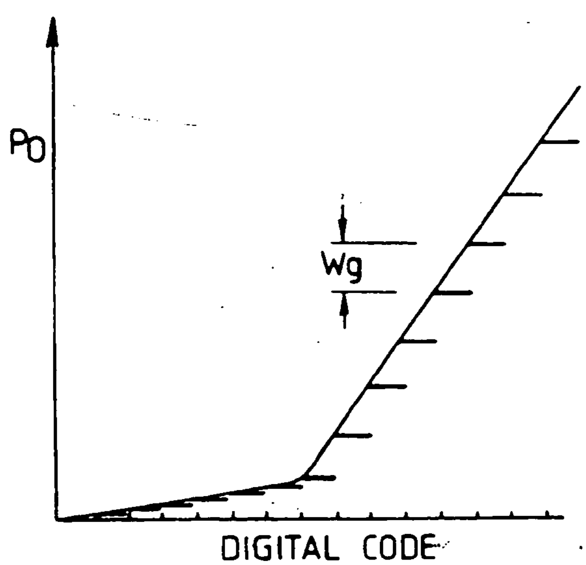


FIG.5b

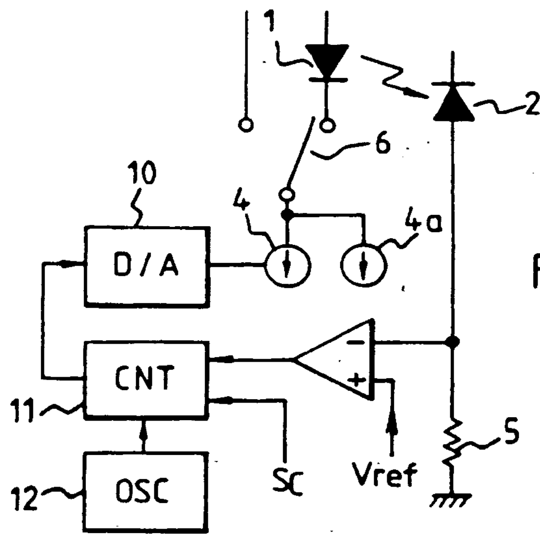


FIG. 6

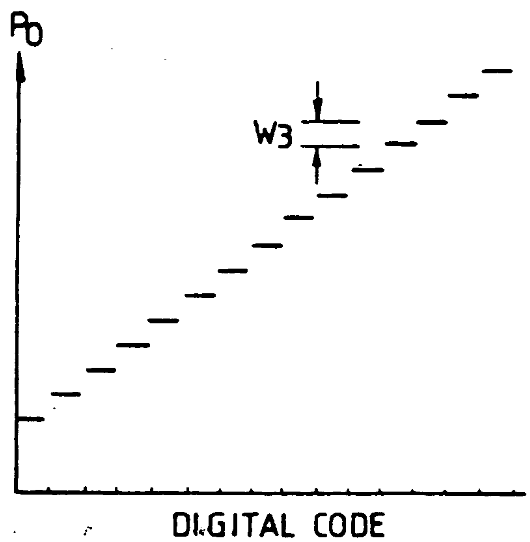


FIG.7a

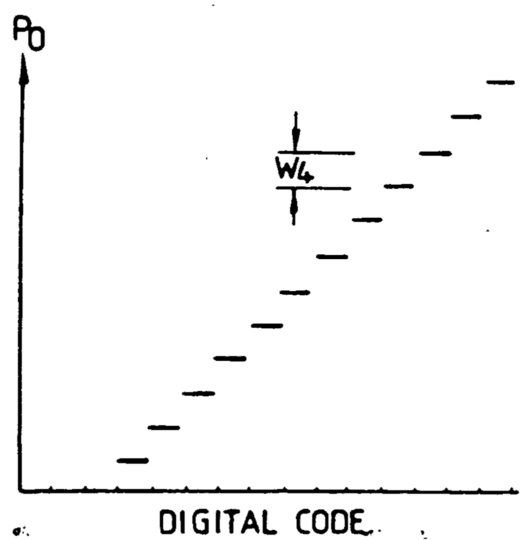
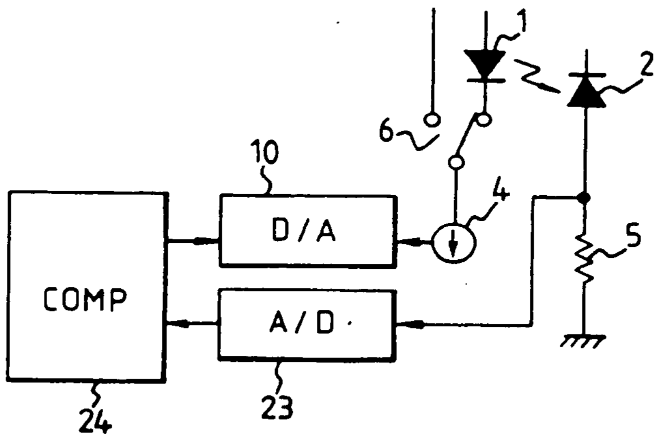
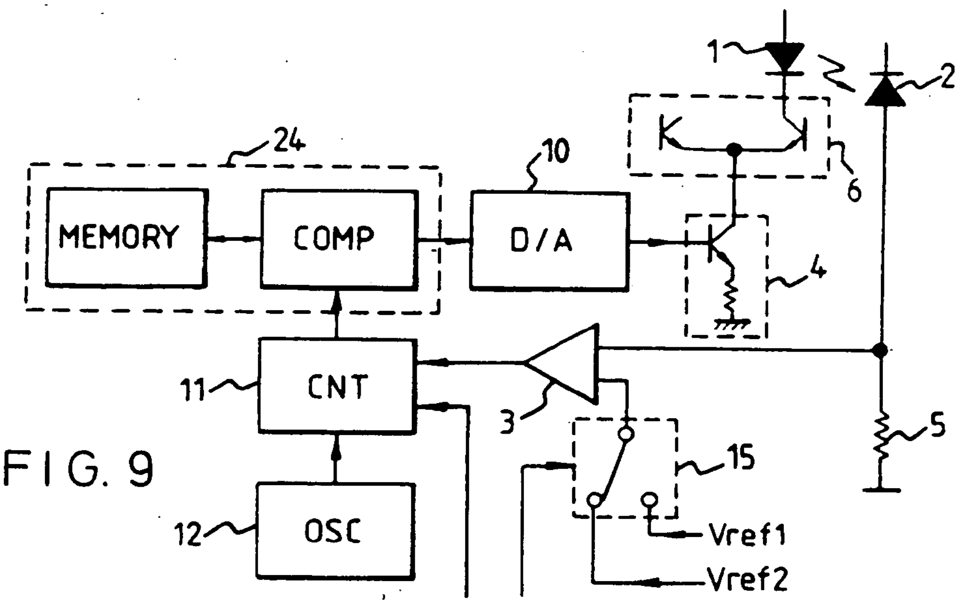


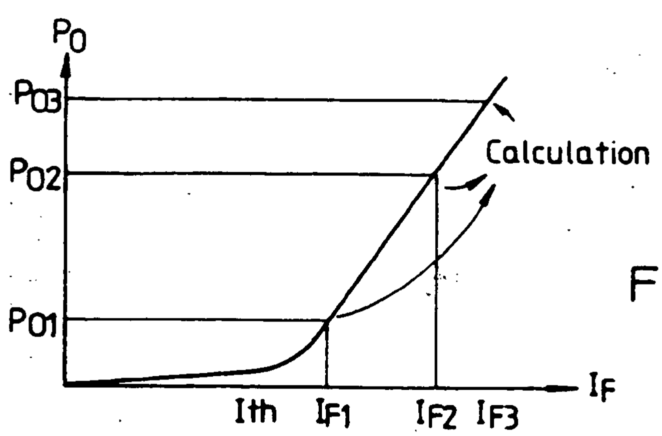
FIG.7b



F I G. 8



F I G. 9



F I G. 10

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 20 1060

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	US-A-4 692 606 (M.SAKAI ET AL.) * column 6, line 1 - line 28; figures 1-5 * & JP-A-61 090 539 (...)	1,2,4	H01S3/133
A	EP-A-0 096 341 (HITACHI) * abstract; figures 1,2 *	1,2,4	
A	CA-B-1 210 070 (G.R.CLINTON) * page 5 - page 6; figures 1,2 *	1,2,4	
A	EP-A-0 061 034 (IBM) * page 7 - page 8; figures 1-4 *	1,2,4	

TECHNICAL FIELDS SEARCHED (Int. Cl.4)

H01S

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 MAY 1992	MALIC K.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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